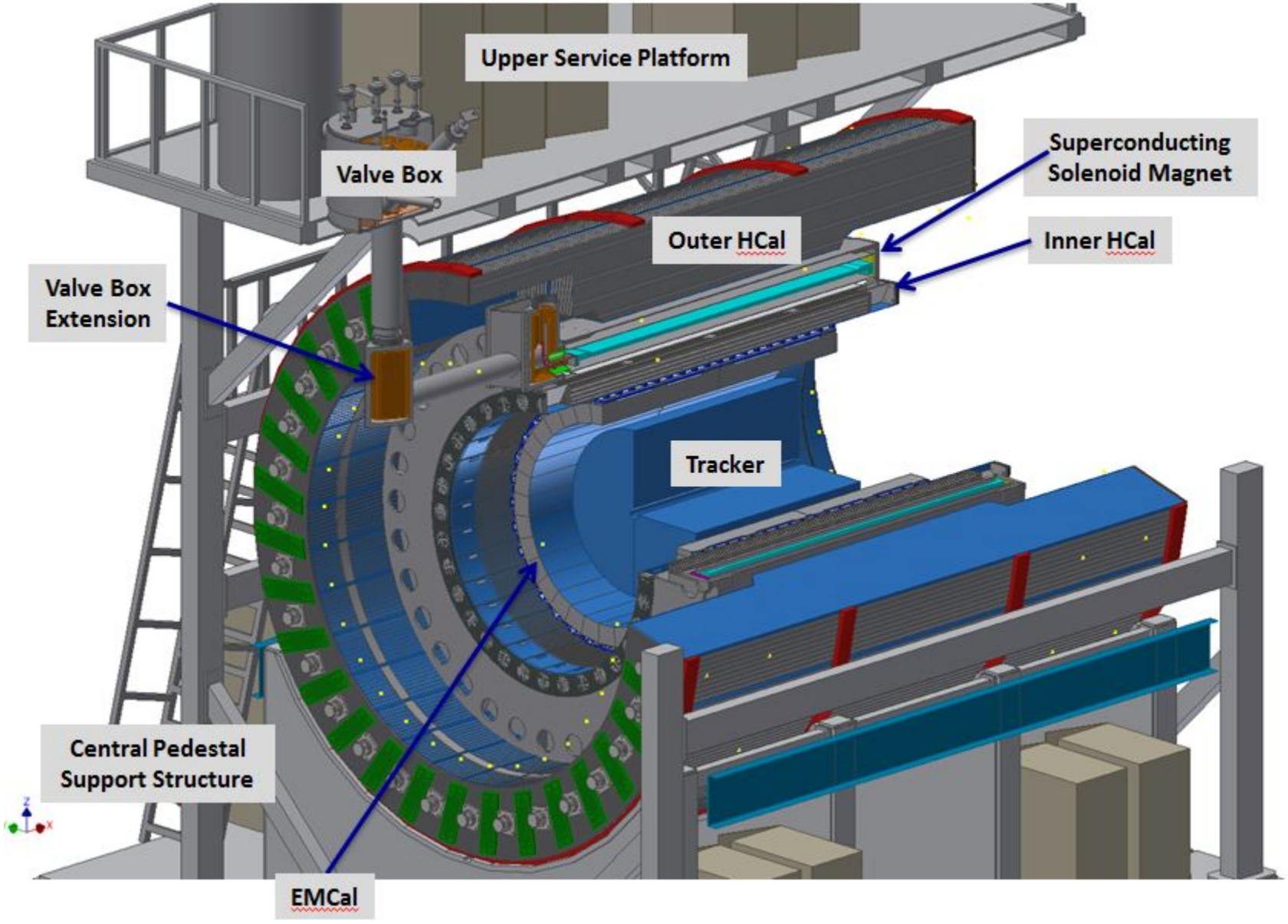
Overview of R&D and prototypes

John Haggerty

The sPHENIX detector concept

- **Uniform acceptance** $|\eta|<1.1$ and $0<\phi<2\pi$
- **Superconducting solenoid** enabling high resolution tracking
- Compact **electromagnetic calorimeter** allowing fine segmentation at a small radius
- **Hadronic calorimeter** doubling as flux return
- **Solid state photodetectors** that work in a magnetic field, have low cost, do not require high voltage, are physically small
- **Common readout electronics** in the calorimeters
- **15 kHz recorded** in A+A allows for large unbiased data sample
- **High resolution tracking** within an 80 cm radius
- Utilization of infrastructure in an **existing experimental hall** (cranes, rails, beam pipe, power, network…)


Upper Service Platform
Valve Box
Superconducting Solenoid Magnet
Outer HCal
Inner HCal
Valve Box Extension
Tracker
Central Pedestal Support Structure
EMCal

R&D history

- Workfests leading up to the July 1, 2014 DOE Science Review were used to develop concepts, simulation, and plan prototypes
  - 12-Oct-2011 CU Boulder
  - 25-Jan-2012 UT Knoxville
  - 20-Feb-2012 Columbia
  - 12-Nov-2012 CU Boulder
  - 20-May-20 13 Santa Fe
  - 29-Jul-2013 RIKEN
  - 31-Mar-2014 Livermore
- First beam test of concepts for HCAL and EMCAL Feb 5-26, 2014 in T-1044 at FTBF
- Second prototypes of HCAL and EMCAL under construction now for beam test April 4-May 3, 2016
- Radiation damage tests of SiPM's, cosmic ray testing of HCAL tiles and EMCAL towers, manufacturing trials

How can I find out stuff?

- Subscribe to the list servers
  - https://lists.bnl.gov/mailman/listinfo/sphenix-tracking-l
  - https://lists.bnl.gov/mailman/listinfo/sphenix-emcal-l
  - https://lists.bnl.gov/mailman/listinfo/sphenix-hcal-l
  - https://lists.bnl.gov/mailman/listinfo/sphenix-electronics-l
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  - https://lists.bnl.gov/mailman/listinfo/sphenix-magnet-l
  - https://lists.bnl.gov/mailman/listinfo/sphenix-forward-l
  - https://lists.bnl.gov/mailman/listinfo/sphenix-eic-l
- Download some code
  - https://github.com/sPHENIX-Collaboration
- Study the Wiki
  - https://wiki.bnl.gov/sPHENIX
- Look at the document database
  - https://docdb.sphenix.bnl.gov
- Check the meeting calendar and attend a meeting
  - https://indico.bnl.gov/categoryDisplay.py?categId=65
  - There's a Google calendar linked from "Meetings" on the Wiki

Who do I talk to?

- Simulations
  - Core development
    - Chris Pinkenburg (HCAL +)
    - Jin Huang (EMCAL +)
    - Mike McCumber [LANL] (Tracking +)
  - Detector specific
    - Magnet
      - Achim Franz, Nils Feege [SBU]
    - EMCAL
      - Jin Huang, Anne Sickles [UIUC]
    - HCAL
      - John Lajoie [ISU], Abhisek Sen [ISU], Xiaochun He [GSU], Megan Connors [GSU], Chris Pinkenburg
    - Tracking
      - Mike McCumber [LANL], Tony Frawley [FSU], Alan Dion [SBU]
    - "BB" minbias trigger detector
      - Martin Purschke

But who do I talk to about detectors?

- Magnet
  - Achim Franz, Kin Yip, Paul Giannotti
- EMCAL
  - Craig Woody, Sean Stoll, Anne Sickes [UIUC], Vera Loggins [UIUC], Jin Huang, Chris Cullen
- HCAL
  - John Lajoie [ISU], Edward Kistenev, Xiaochun He [GSU], Megan Connors [GSU], Jamie Nagle [Colorado], Ron Belmont [Colorado], Abhisek Sen [ISU], Don Lynch, Rich Ruggiero
- Tracking
  - Pixels
    - Yasuyuki Akiba [RIKEN], Gaku Mitsuka [RIKEN]

  - "Outer" strips
    - Yasuyuki Akiba [RIKEN], Gaku Mitsuka [RIKEN], Rachid Nouicer, FVTX collaboration
  - MAPS
    - Mike McCumber [LANL], LANL group
  - TPC
    - Tom Hemmick [SBU], Axel Drees [SBU], Ron Soltz [LLNL], Takao Sakaguchi
- "BB" minbias trigger detector
  - Martin Purschke, Mickey Chiu

Who do I talk to about electronics?

- Calorimeter electronics
  - SiPM's
    - Sean Stoll, Craig Woody
  - Amplifiers and controllers
    - Eric Mannel, Steve Boose
  - Digitizer and trigger primitives
    - Cheng-Yi Chi [Columbia], Eric Mannel
- Tracking electronics
  - Pixels
    - Yasuyuki Akiba [RIKEN], Gaku Mitsuka [RIKEN]
  - Strips
    - Yasuyuki Akiba [RIKEN], Gaku Mitsika [RIKEN], Itaru Nakagawa [RIKEN], FVTX group
  - TPC
    - Takao Sakaguchi, Tom Hemmick [SBU], Ron Soltz [LLNL]
- "BB" minbias trigger detector electronics
  - Cheng-Yi Chi [Columbia]

Ongoing R&D efforts

- Simulation
- Magnet testing
- Electromagnetic calorimeter (W-scintillator SPACAL)
- Hadronic calorimeter (steel-scintillator tilted plate)
- Calorimeter electronics
  - SiPM
  - Digitizer
  - Amplifier
- Tracking
  - Pixels
  - Strips
  - MAPS
  - TPC

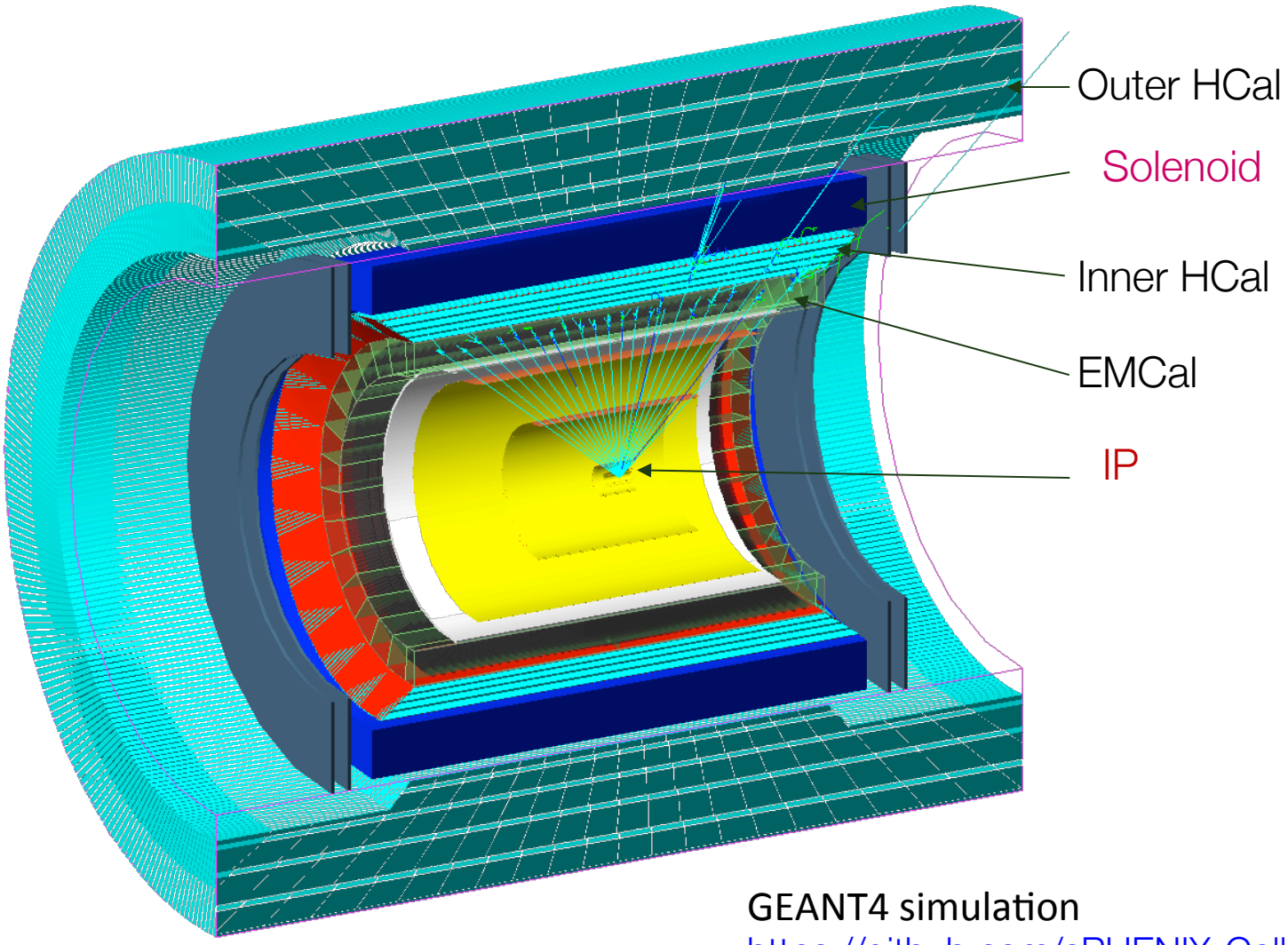
Simulation

Most of what we are going to know about the performance of the detector will come from simulation—of physics processes, detector characteristics, of electronics, of light collection…

This is the single biggest place where we need the efforts of a focused collaboration

A new beginning

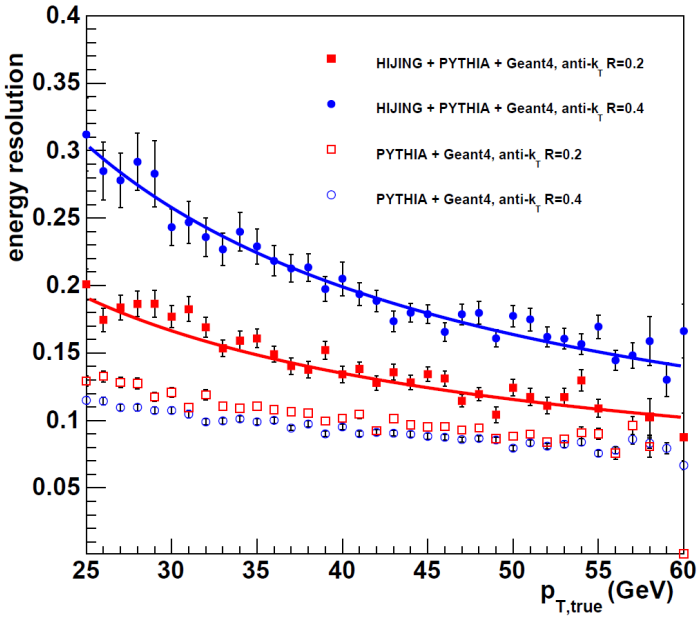
- A small core group (Chris, Jin, Mike) has done a lot of the heavy lifting, creating the structure and generating event samples starting with Workfests as far back as 2011
- Many others have contributed code and used code and data

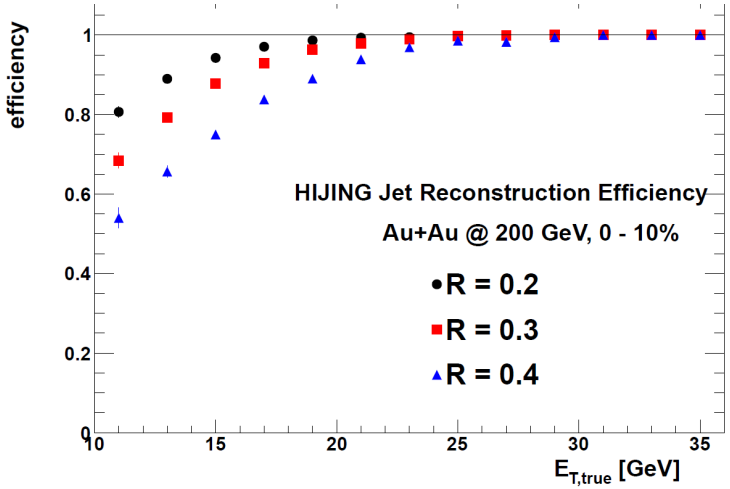


GEANT4 simulation
https://github.com/sPHENIX-Collaboration

Jets in central Au+Au

- Adapted unfolding procedures developed by ATLAS and CMS to RHIC
- GEANT4 Monte Carlo
- Good efficiency, purity, resolution





Simulation and prototyping

- There has been considerable effort devoted to connecting the prototypes with simulation
- Xiaochun and his group have been the pioneers (see HCAL prototype technote) and are gearing up for a second round

Issues and needed work

- Both calorimeters have depth dependent sampling fraction and that needs more study and characterization both in single particle, jet, and embedded jet events
- We need studies of real world effects (missing fibers, low light production, variability in light output of tiles, dead sensors, miscalibration)
- "Value engineering" and design optimization questions are needed to compare options (for example, 4 tiles/tower in HCAL, or reducing the thickness of the EMCAL or HCAL slightly, or even more radical possibilities)
- High resolution tracking only became a major detector goal after the Science Review and needs a lot of thinking and simulation--Tony, Tom, and Mike have pushed on this, but there's a lot more work to do

Lots of opportunities

- From detector basics (light production, light transmission, single particles, beam tests of prototypes) to proto-physics analysis, many opportunities for collaboration efforts for the computationally savvy
- We might need a task force to create a prioritized list of studies that need to be done
- There is a natural place to report on these studies at the simulation and detector meetings
- Completed documents like what Xiaochun and Liang did for the HCAL beam test provide input to the design reports that we will need to produce

BaBar superconducting solenoid

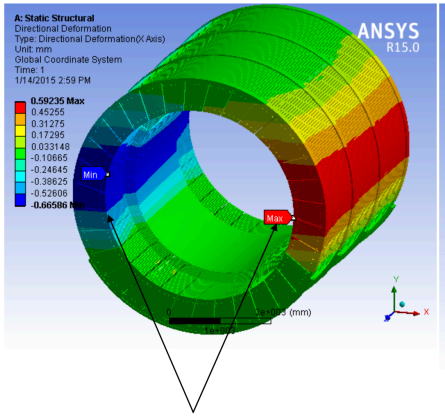
MAGNET

BaBar solenoid

- BaBar magnet secured from SLAC after SuperB canceled, arrived at BNL in February 2015
- Considerable additional equipment also acquired (power supplies, dump resistor, quench protection, cryogenic equipment)
- SMD and CAD preparing it for low power cold test
- Well suited to our needs without compromises
  - 1.5 T central field
  - 2.8 m diameter bore
  - 3.8 m long
  - $1.4X_0$ coil+cryostat

Engineering

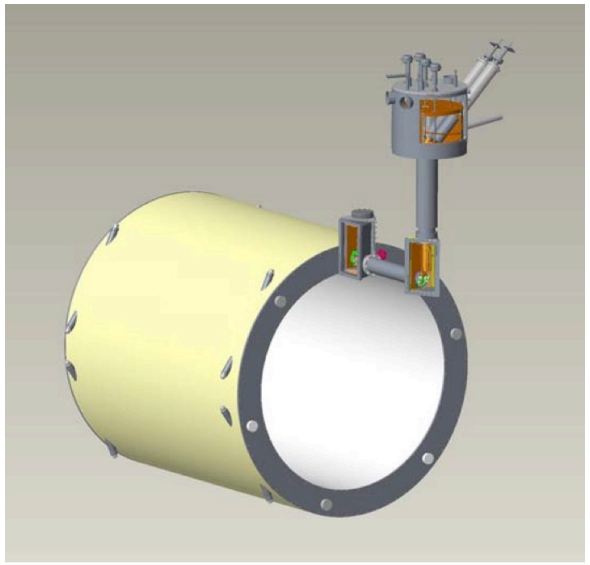
- Structural analyses of assembly
- Magnetic field and force calculations
- Design of cryogenic plant
- Assembly plans and structural analysis



X DEFORMATION +/- 0.6mm

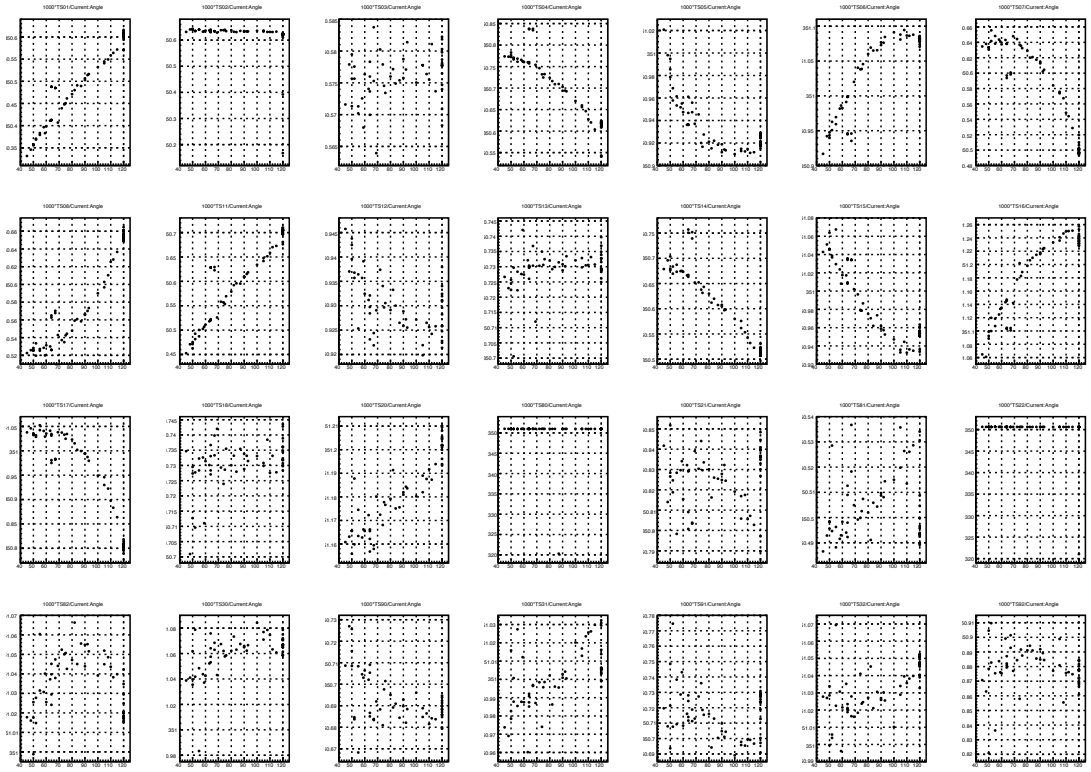
Y DEFORMATION 1mm MAX

FINAL ASSEMBLY DEFORMATION IS WITHIN TOLERANCE

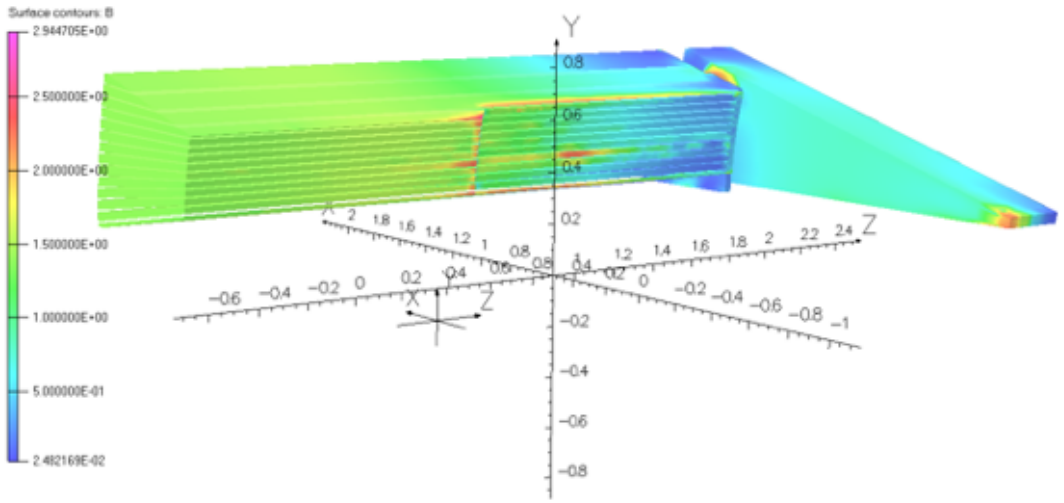


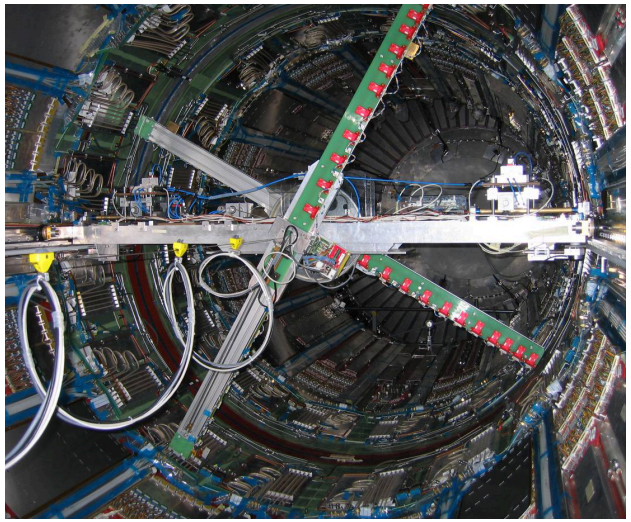
Magnet development

- Achim Franz has done a superb job leading our magnetic field calculations and planning for mapping, could use a collaborator (Wuzheng Meng, who did all the initial 3D models is retiring)
- Kin Yip is the manager of the Physics/CAD/SMD project
- Useful to work with instrumentation to understand the low field test (coming up very soon) and the high field (next year) test; Paul Giannotti has worked with CAD/SMD engineers on this

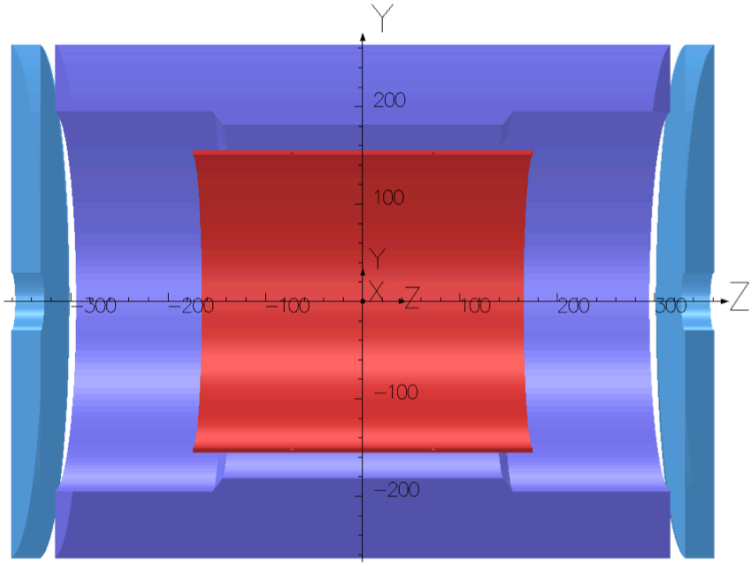


Data from strain gauges acquired by Piyush Joshi and Paul Giannotti during the rotation of the solenoid





2D and 3D magnetic field calculations and mapping concepts from Achim



Issues and needed work

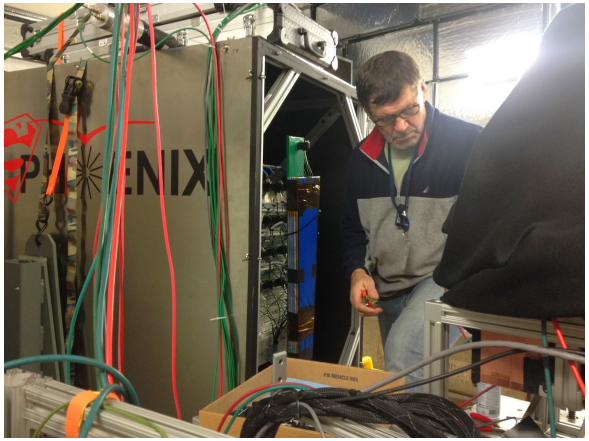
- Magnetic field calculations as input to simulations already noted
- Field uniformity and alignment issues (mainly relevant to TPC tracking)
- Development of mapping hardware, monitoring hardware, other instrumentation for operation in the experiment
- If there is additional superconducting magnet engineering capability in the collaboration, we need to tap into it

Electromagnetic and Hadronic Calorimeters

CALORIMETRY

Prototypes

- First round of EMCAL and HCAL prototypes built at BNL in 2013 and tested at Fermilab (FTBF T-1044) 5-26 Feb 2014
- First tungsten-fiber calorimeter read out with SiPM's by the collaboration
- First tilted plate/extruded scintillator read out with WLS fiber and SiPM's by the collaboration (note design was based on needs of a new 70 cm radius magnet)

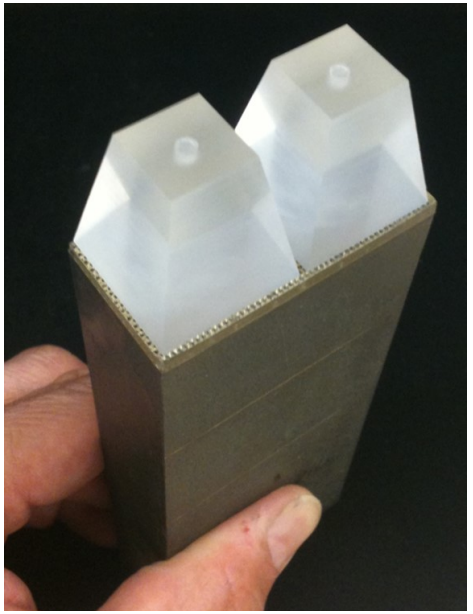


Prototype calorimeters and electronics developed for 2014 beam test

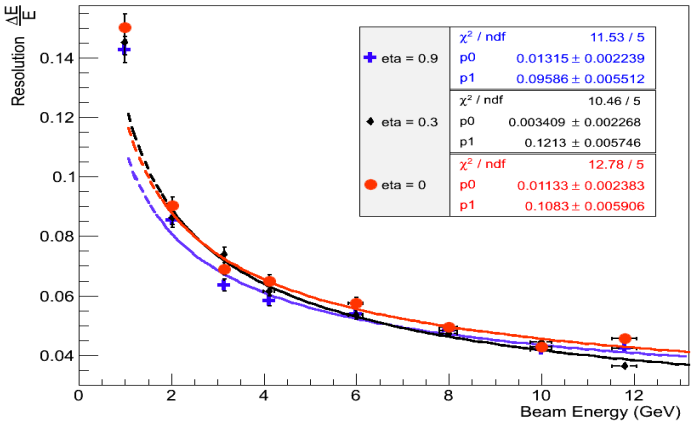
Round 2: April 2016

Electromagnetic calorimeter

- Tungsten-scintillating fiber SPACAL
- Radiation length of ≈7 mm allows it to be inside the solenoid where only the material of the tracker is in front of it
- Beam tested by UCLA group
- Development of projective geometry which could improve e/π separation needed for the Upsilon measurements
- Readout on inner radius of EMCAL with 4 3x3 mm SiPM's
- On-detector electronics limited to preamps, bias control and temperature monitoring

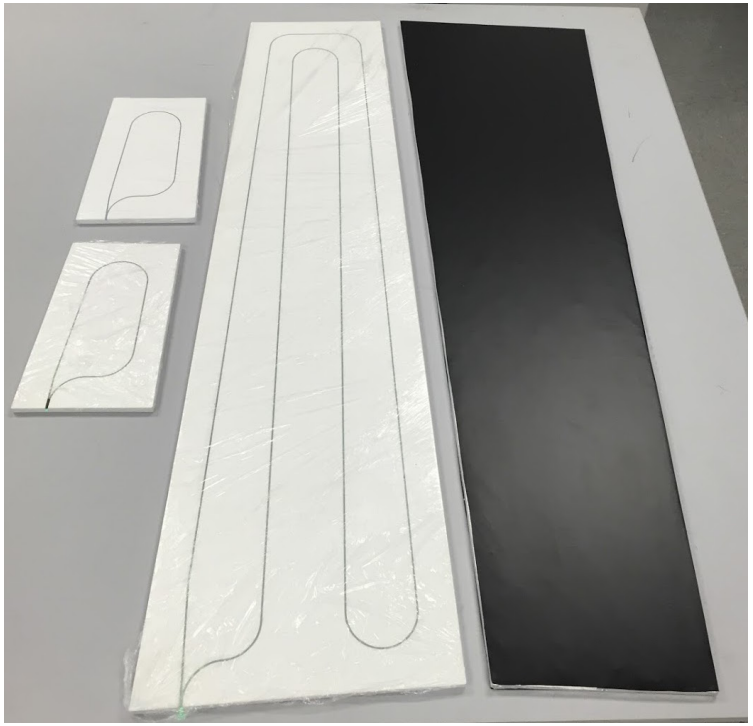


EIC BEMC at eta=0.9, 0.3, 0, Energy Resolution



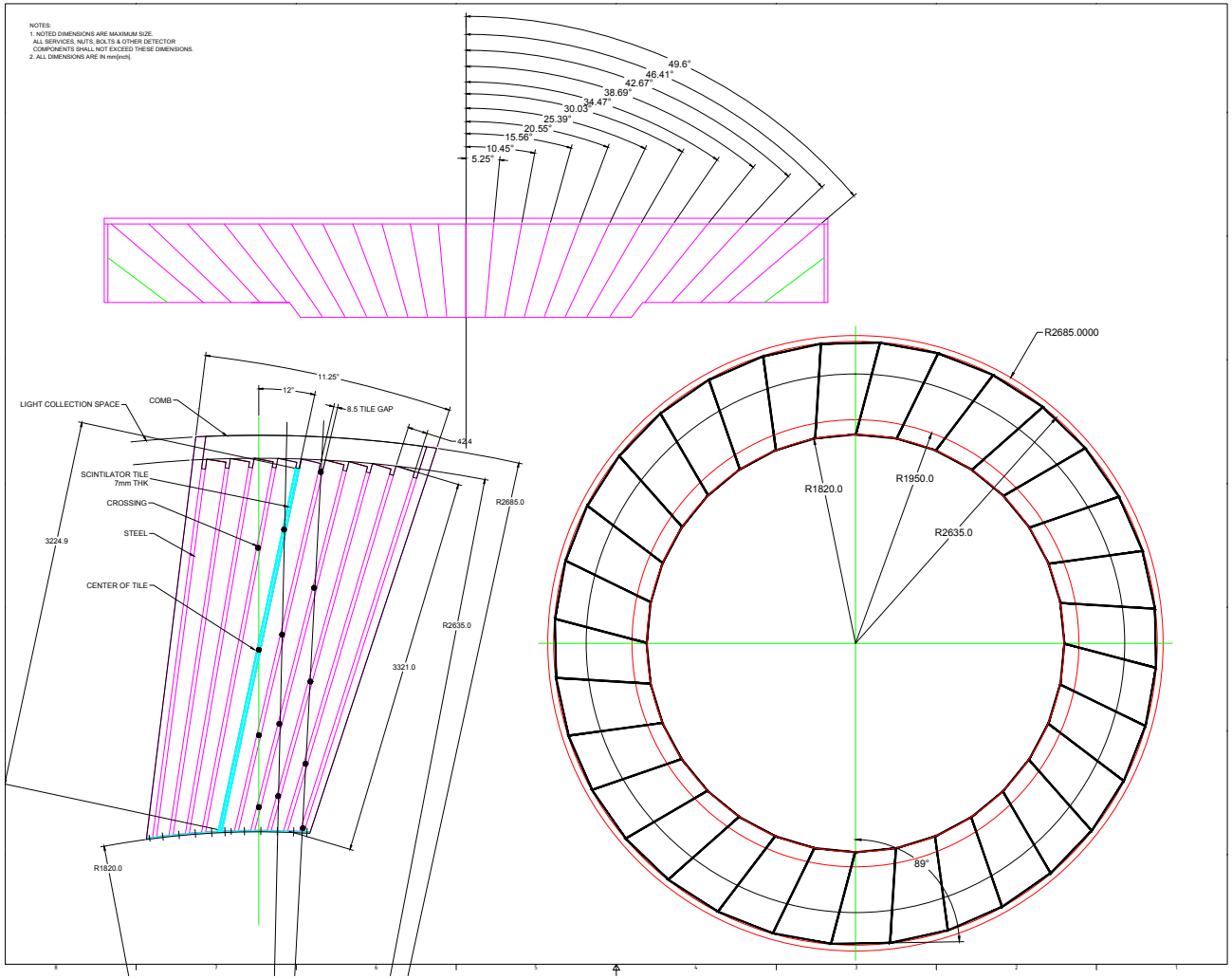
Hadronic calorimeter

- Extruded 7 mm polystyrene scintillator tiles with embedded 1 mm WLS fiber
- SiPM's on the outer radius (one per tile)
- Five tiles in Φ ganged together into tower
- Outer tiles ≈80 cm long
- The outer hadronic calorimeter returns the flux of the magnet

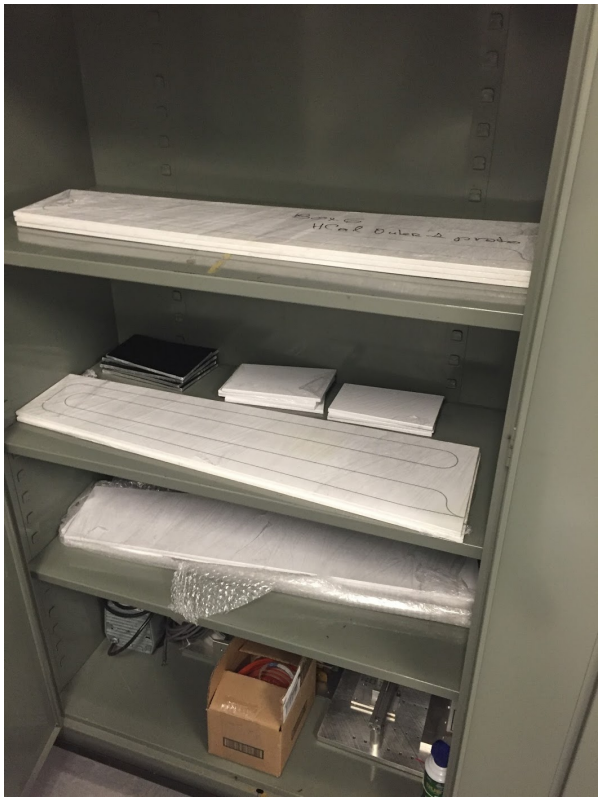


Prototype tiles (Uniplast)

Outer HCAL


NOTES:
1. NOTED DIMENSIONS ARE MAXIMUM SIZE.
ALL SERVICES, NUTS, BOLTS & OTHER DETECTOR
COMPONENTS SHALL NOT EXCEED THESE DIMENSIONS.
2. ALL DIMENSIONS ARE IN mm[inch].
49.6°
46.41°
42.67°
38.69°
34.47°
30.03°
25.39°
20.55°
15.56°
10.45°
5.25°
11.25°
12°
8.5 TILE GAP
424
LIGHT COLLECTION SPACE
COMB
SCINTILATOR TILE
7mm THK
CROSSING
STEEL
CENTER OF TILE
3224.9
R2685.0
R2635.0
3321.0
R1820.0
R2685.0000
R1820.0
R1950.0
R2635.0
89°

HCAL steel in Physics high bay waiting for assembly



Abhisek and Megan are overseeing preparation of tiles order by Edward

Issues and needed work

- Simulation issues already discussed
- EMCAL tower manufacturing techniques (including 1D and 2D projective towers)
- EMCAL calibration system (current concept is LED + data)
- EMCAL light collection optimization (Monte Carlo and experiment)
- Development of EMCAL tower test criteria and procedures
- HCAL SiPM holders
- HCAL calibration system (current concept is LED + cosmic); selection and placement of LED
- Light-tighting

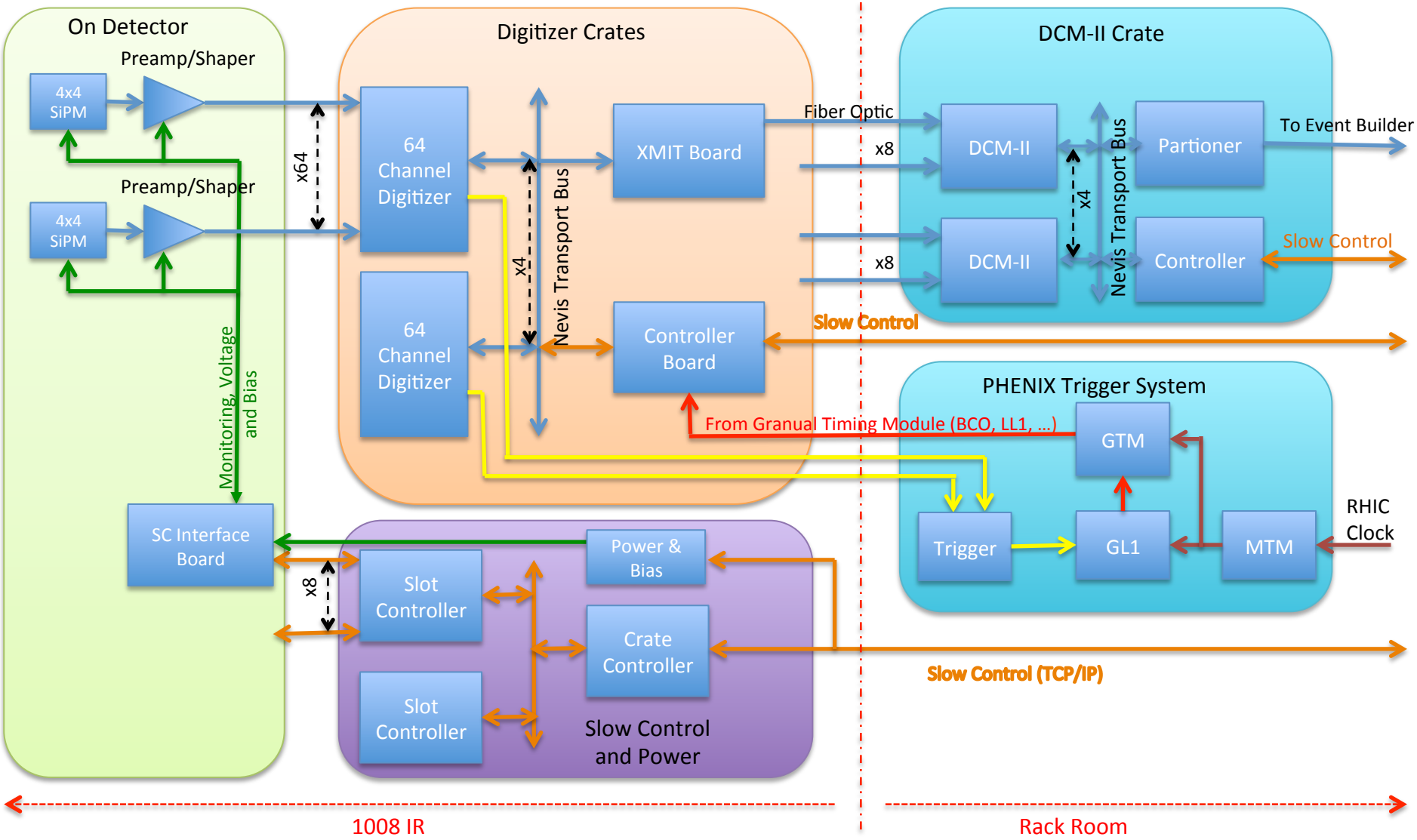
Sensors, preamplifiers, and digitizers (a little about DAQ and trigger)

CALORIMETER ELECTRONICS

Electronics Concept

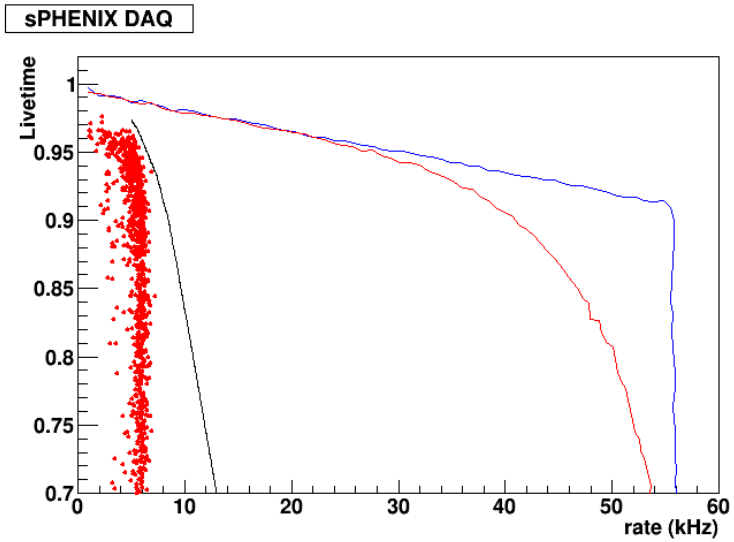
- Based on PHENIX experience
- Maintain as much of the PHENIX DAQ as reasonable
  - Event Builder, DCM-II, GTM, GL1
  - Slow control infrastructure
  - Monitoring and data logging infrastructure
- Similar compact design for EMCAL and HCAL
  - SiPM/tower: EMCAL: 4, HCAL: 5
  - Analog front end on the detector
  - Digitization in the IR, digital data to counting house
- Simple, reliable front end electronics on the detector, minimizing connections
- Commercial components

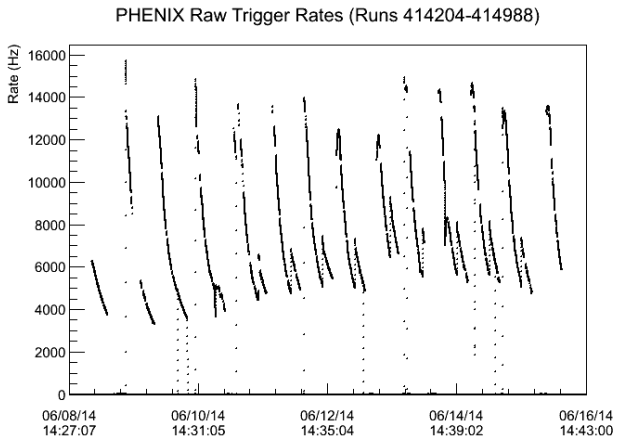
Calorimeter Electronics Overview



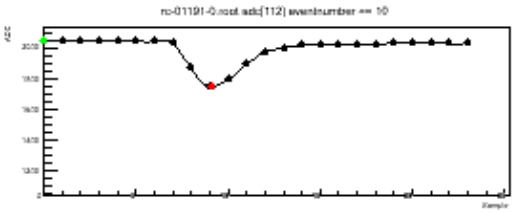
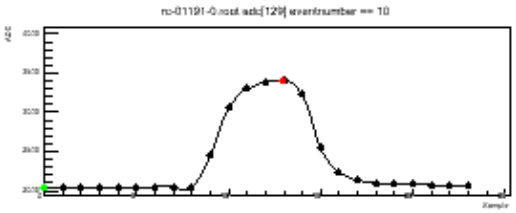
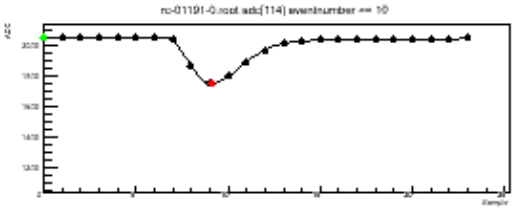
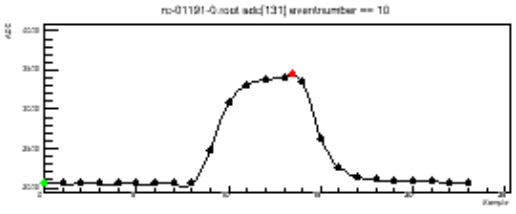
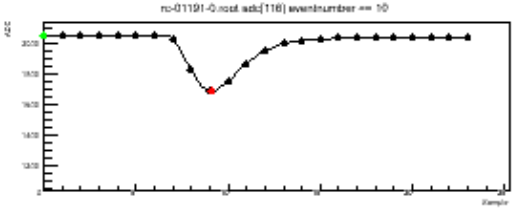
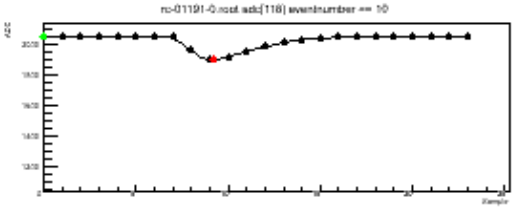
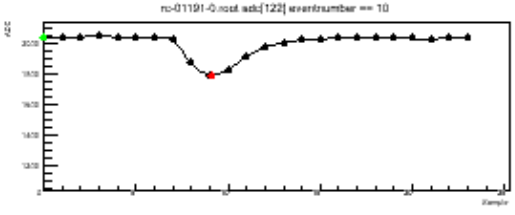
Triggering and calibration

- Level 1 triggering
  - Trigger primitives every crossing
  - Level 1 decision in 40 clock ticks (4 μs)
  - Buffer 4 consecutive events
  - 15 kHz accept rate
- Calibration system
  - Pulse injection into front end
  - Light pulser into SiPM's
  - Track gain changes from manufacture through operation

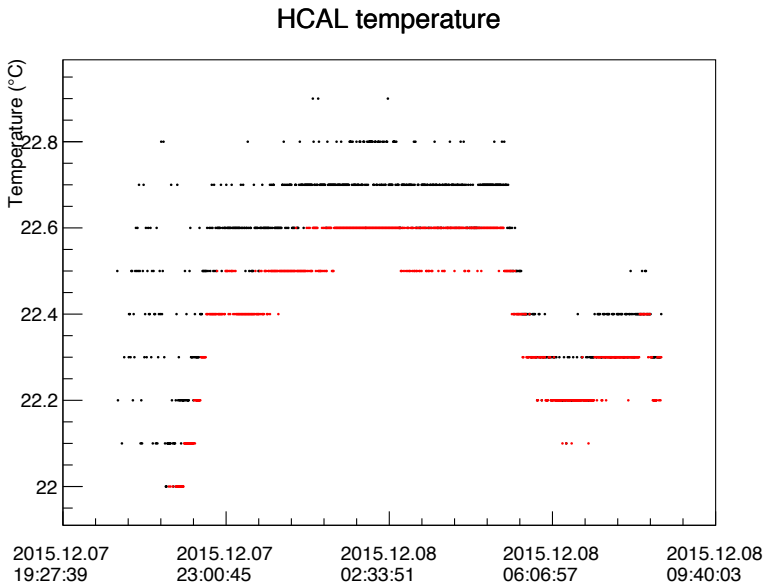




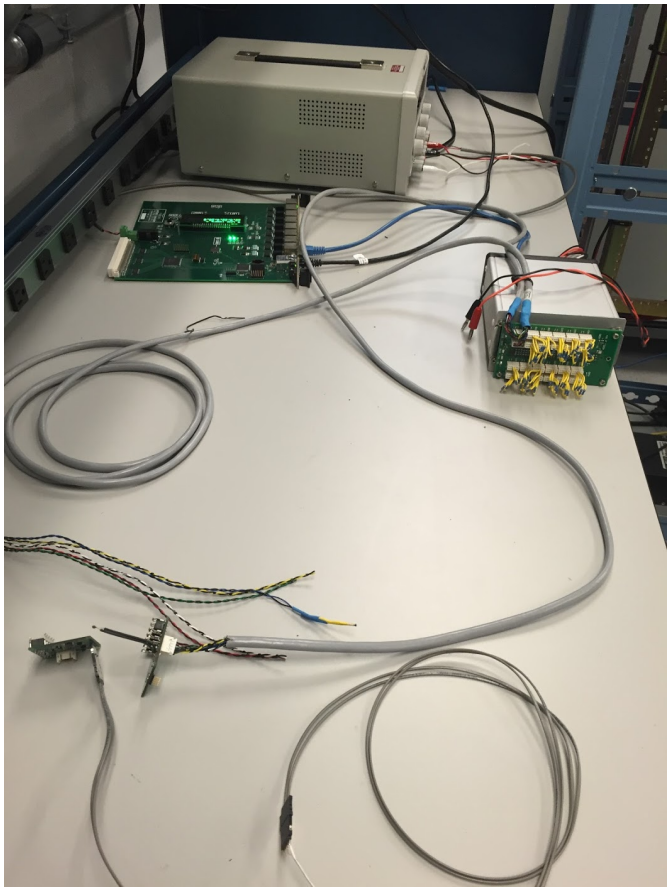
Run 14 Au+Au
(about half of maximum projected)

60 MHz waveform digitizers being developed at Columbia are used for readout—opportunities to work with Chi on DAQ software/firmware



Software and hardware development in progress… Steve, Chi, and Eric



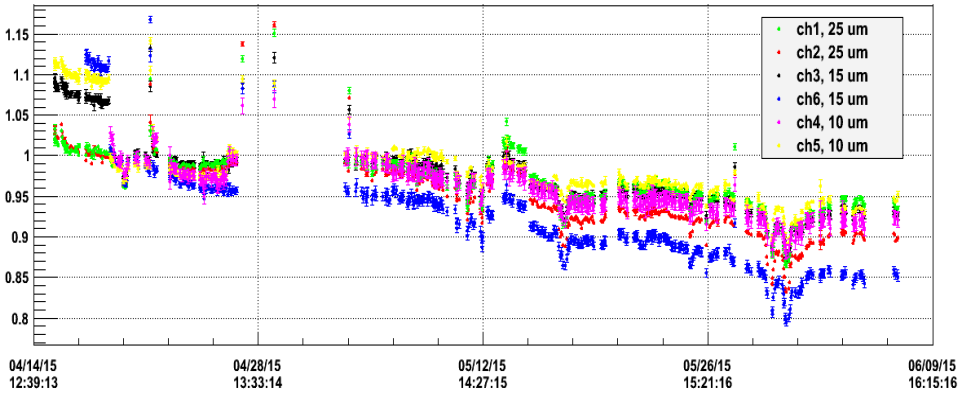
Steve Boose's HCAL controller under test

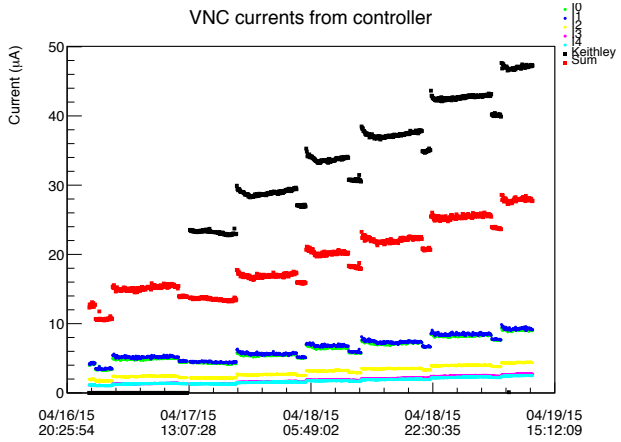
Calibration and triggering

- We have concepts for calibration which can be explored in the upcoming beam test
- We have defined trigger primitives that will come from the electronics, but we could use algorithm ideas and development
- Opportunity to conceive trigger hardware—John Lajoie is the architect of the PHENIX trigger system, lots of things to rethink in sPHENIX era

Radiation damage studies

- We have had several rounds of studies of radiation damage in the PHENIX IR and with controlled neutron exposures
- LDRD with Instrumentation Division and Craig Woody, Sean Stoll
- More to be done, both measurements and with cooling design





Issues and needed work

- SiPM radiation damage predictions based on experiments
- Heat removal/cooling of electronics and sensors
- Development and commissioning of new 14 bit Columbia digitizers
- Readout of new digitizers by DCM II's
- Hardware verification of controller capabilities (temperature and current measurement, bias control)
- Development of scalable control system

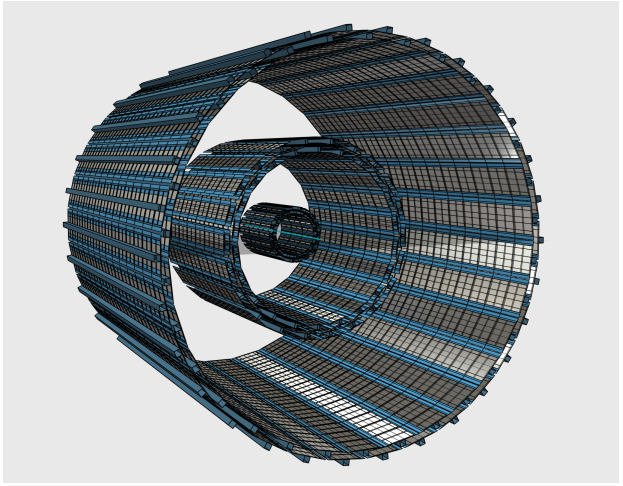
Options for tracking: all silicon or silicon + small TPC

TRACKING

Tracking options compared

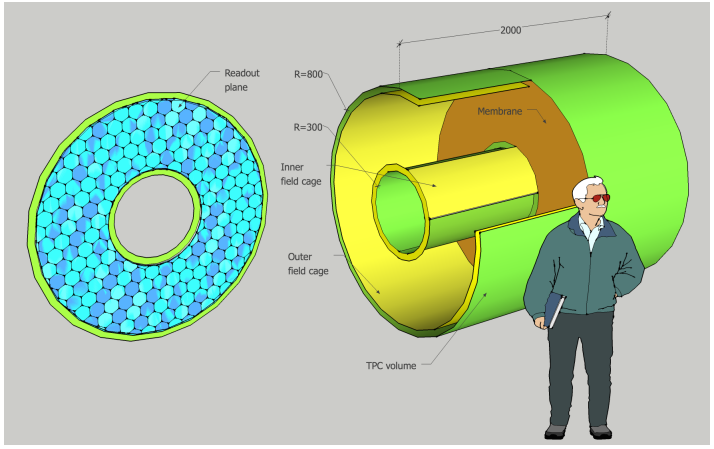
Si tracker

- 7 layers strips and pixels
- Achieves design goals of pattern recognition and 100 MeV mass resolution on Upsilon states
- Total thickness ≈0.1X_0



TPC + inner Si layers

- 80 cm outer radius TPC
- Inner Si detector
- TPC electronics following from ALICE upgrade



Tracking R&D

- Our biggest open question is the design of a tracking system that gives us the Upsilon program at a reasonable cost
- There are 5 talks on tracking concepts, simulation, and technologies today and tomorrow

Minimum bias trigger detector, system engineering, forward spectrometer

OTHER THINGS

Beam-Beam detector

- Ideas on a new BB counter for minimum bias triggering and vertex determination are being considered
- Possibility of Columbia to design high resolution TVC which would allow common readout with calorimeters
- A number of smaller groups could conceivably collaborate on this project

Issues and needed work

- Simulation studies already noted
- Detector technology proposal
- Conceptual design of TVC including triggering capability
- Cost estimate and project plan

Forward instrumentation

We have tried to not preclude additional instrumentation in the forward direction for future spin and EIC experiments (perhaps not well enough—maybe Christine and Sasha's talk will make that clearer), but it *is* clear that we must make a conclusive case for the design of the central detector first

Ask not what sPHENIX can do for you….

- From simulation design to simulation analysis, from designing and building detectors to beam tests, there is lots to do
- Whatever your expertise or interest, there is work to do